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Battery Energy Storage System-based Outage Management for Remote Customers

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SUMMARY

Developing reliable strategies for grid outage management is an ongoing challenge to the power utility industry. This paper focuses on developing a battery energy storage system (BESS) based outage management technique to increase the reliability of the grid at chosen customer target points. The benefits of having an energy storage system connected at the utility side and the customer side over traditional outage management strategies has been explained in this paper. An example of using IEEE 13-bus feeder with active distribution generation resources such as a photovoltaic (PV) system and BESS has been simulated with a three-phase fault, and the model's capability to establish the resiliency of the storage system was studied. Simulink model has been developed to understand the behaviour of the battery storage system to cater to the residential loads in the event of an upstream grid outage and the coordination between BESS and PV generation.

KEYWORDS

Battery Energy Management System, Distributed Generation, Photovoltaic, Fault Detection and Isolation, Microgrid, Outage Management

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INTRODUCTION

One of the key challenges faced by the power industry is to improve the reliability of the power grid and shielding customers from possible cases of power outage by employing new resilient strategies to detect the outage, isolate the faulty system, and reduce the power interruption at target locations by commissioning alternative sources of active distributed energy resources (DER) and battery energy storage systems (BESS). As the complexity of the network topology increases, the strategy of outage management becomes more demanding. It is also essential to keep track of the cost for the outage management, especially while working at some remote locations.

In the event of an upstream outage, smart meters [1], automatic switches, and fault indicators, etc., with communication abilities, send the information regarding the fault line and fault location [2] to the Supervisory Control and Data Acquisition (SCADA) system or the Outage Management System (OMS) of distribution networks [3]. Advanced metering infrastructures (AMI) can detect the outages by the voltage and current variations on distribution lines [4]. The utility then responds for fault isolation and power restoration. Traditional methods for power restoration include a provision of alternative distribution lines to act as a backup power supply in case of outages. In addition, underground cables can be used instead of overhead lines, or bare conductors can be replaced with insulated conductors. The fault rate can further be reduced by preventive maintenance such as tree trimming and by installing automatic in-line protection and continuous alternative supply, however, improving service quality is costly [5].

Microgrid-based solutions utilizing a set of emergency diesel generators can provide much higher levels of reliability in case of outages [6]. One of the disadvantages of consuming power from the diesel generator is the adverse impact of using fossil fuels on environmental protection. Additionally, if backup power is required for multiple days, stand-alone building-tied emergency diesel generators cannot be relied on by themselves to provide backup power for critical loads [7].

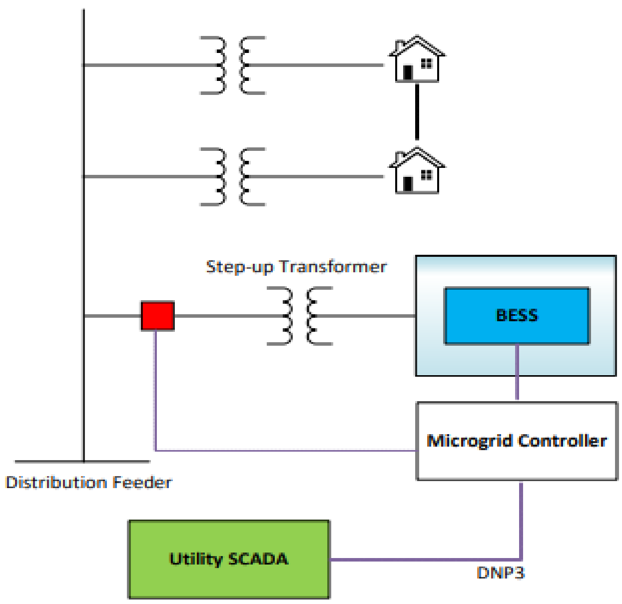

Fig. 1 Battery Energy Storage System for Outage Management in Residential Areas

Distribution feeders on certain locations have the capability to connect to another feeder loop servicing nearby locations. The feeders powering the remote areas discussed in this paper are towards the edge of the utility's service territory, where there are no options to loop with the same feeder or create ties with other feeders. The battery energy-based storage solution for outage management has been selected for this specific project as other methods are either too expensive or are not feasible for the chosen target customers. In addition to the BESS, a photovoltaic system has also been integrated in the secondary side along with the battery system to support the residential loads during outages [8-9].

This paper focuses on the advantages of developing a BESS-based outage management for remote locations. Contrary to traditional outage management solutions, the BESS can improve the reliability of the grid on the customer side by acting as an alternative power supply in islanded mode during the outage and automatically reconnect to the grid, following the restoration of the upstream voltage. The specific location of interest has been chosen by ComEd based on the data obtained from customers in locations that experienced significant or long hours of outages in the past 5 years. Fig. 1 represents the schematics of the planned outage management system using a battery storage system in the chosen residential area.

The next two sections explain the basic concept of the BESS and PV. The fourth section of the paper shows the example of IEEE 13-bus feeder with DER that has been used for the simulation studies. The simulation results of this example system are demonstrated and discussed in Section 5. Conclusions regarding the advantages of the method employed for the outage management are presented in the last section.

PHOTOVOLTAIC BASED DISTRIBUTION ENERGY RESOURCE

Photovoltaic cells are made up of silicon materials and are connected to form a PV module. The PV outputs DC voltage, which can be connected to power electronic interfaces to obtain AC power [10-11] for the grid or residential loads.

Fig. 2 is a diagram of PV-based distributed generation that can be integrated with the test feeder. Maximum Power Point Tracking (MPPT) control is used to maximize the energy extraction from the PV source [12].

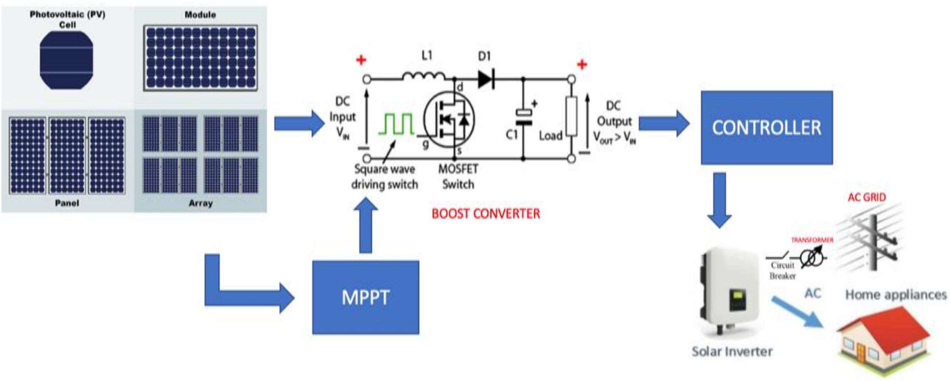

Fig. 2 Implementation of a simple photovoltaic-based DG system

BATTERY ENERGY STORAGE SYSTEM

Batteries are one of the most crucial energy storage systems in the power industry [13]. They are specifically used in the power grid to adjust the active and reactive power and act as an uninterruptible power supply in islanded mode during outages. The maximum energy that can be stored in the battery and used in case of an emergency defines the capacity of the battery. State of Charge (SoC) [14] measures the level of charge of an electric battery relative to its capacity. Fig. 3 represents the schematics of a BESS. The controller is part of the battery management system, which measures the various parameters of the battery (state of charge, state of health etc.) and protects the battery from any external/ internal hazards. The inverter system converts direct current (DC) produced by batteries into alternating current (AC) and supplies the AC power to facilities. Battery energy storage systems have bidirectional inverters that allow for both charging and discharging [15].

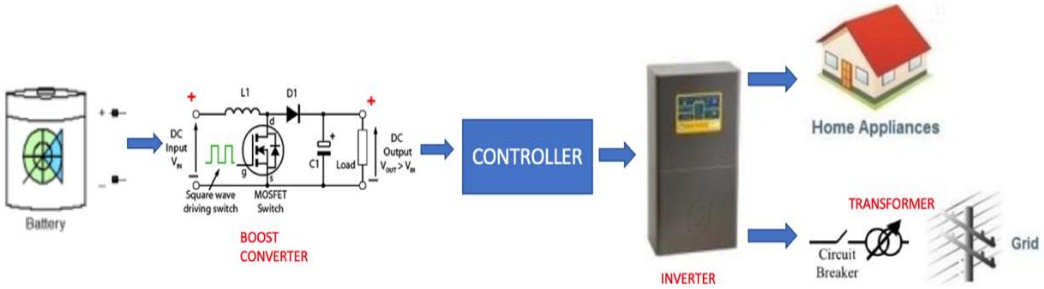

Fig. 3 Implementation of a simple Battery Energy Storage System

The BESS system is also integrated with some Energy Management Systems (EMS). This includes intelligent battery software that uses algorithms [16] to coordinate energy production with computerized control systems that determine when to use the energy to provide power to local loads and when to release it to the grid.

In both the battery system and PV system, the inverter acts as the point of integration between the AC grid and the distribution energy resource. Droop control [17] strategy is sometimes implemented in the control system of the inverter where it regulates the frequency or voltage by adjusting the output active power or reactive power of a controlled asset.

SIMULATION RESULTS

The one-line diagram of the IEEE 13-bus system integrated with battery energy storage system and PV system has been shown in the Fig. 4. The main grid T-1 can supply the power to all loads connected to the distribution line.

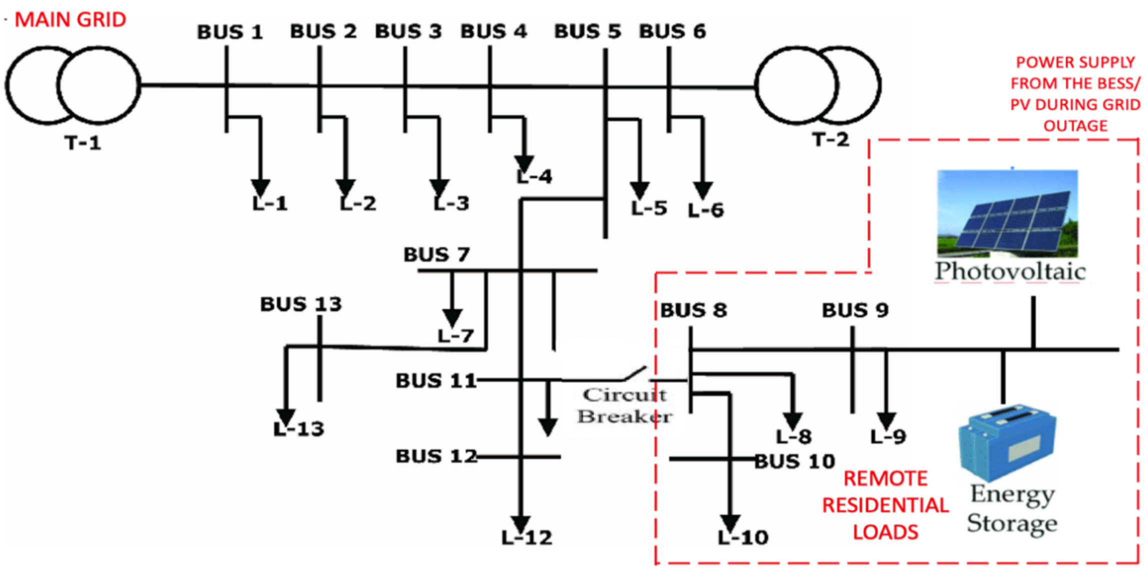

Fig. 4 IEEE 13-Bus System with BESS/ PV Distribution Generation Units

At time=1s, a three-phase fault was simulated in the circuit, which triggers the circuit breaker. This represents a specific case of power outage in the location corresponding to loads 8,9 and 10. The BESS is immediately activated, and the power is drawn from the distributed generation resources to cater to the energy needs of these local loads. The microgrid with BESS and PV goes into an islanding mode until the fault is isolated and power can be restored to this distribution line. Following the restoration, the DERs can automatically reconnect to the grid.

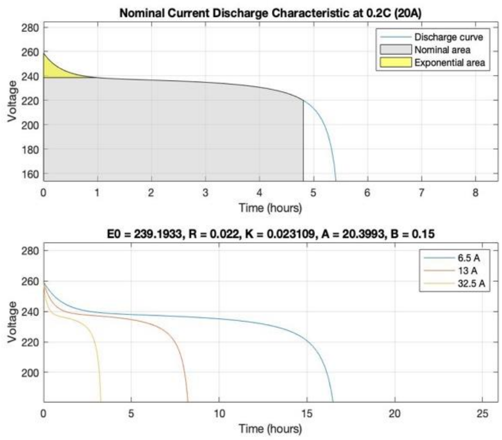

Fig. 5 Battery Discharge Characteristics

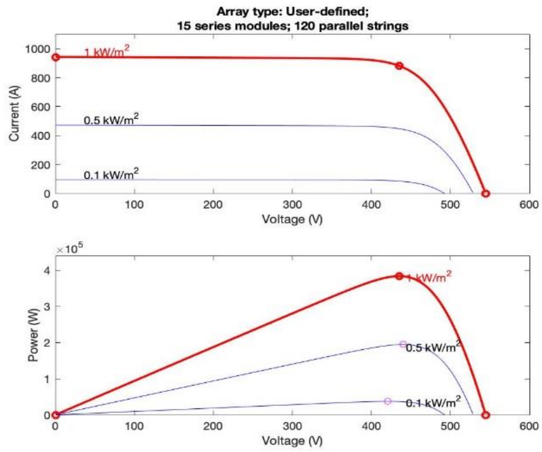

Fig. 6 I-V and P-V characteristics at various irradiances

The test case used for simulation uses a Li-ion Battery [18], and the discharge characteristics of this battery are depicted in Fig. 5. To supply the requisite power to the loads connected on the grid, a PV array with 15 series modules and 120 parallel strings was simulated. For different irradiance measures at a constant temperature of 25 degree Celsius, the I-V and P-V characteristics were plotted in Fig. 6. After the fault is detected and isolated at t = 1 s, the representations of the residential loads, marked by load 8,9 and 10 in the test case, do not receive the required energy from the main grid. In this case, the BESS is used as an alternative power supply and caters to the energy needs of these loads. The slight variation in the three-phase voltage across bus 8 can be seen in Fig. 7. The difference between the peak voltages of the grid supply and BESS supply has been measured to be less than 10% which is within the acceptable range of values.

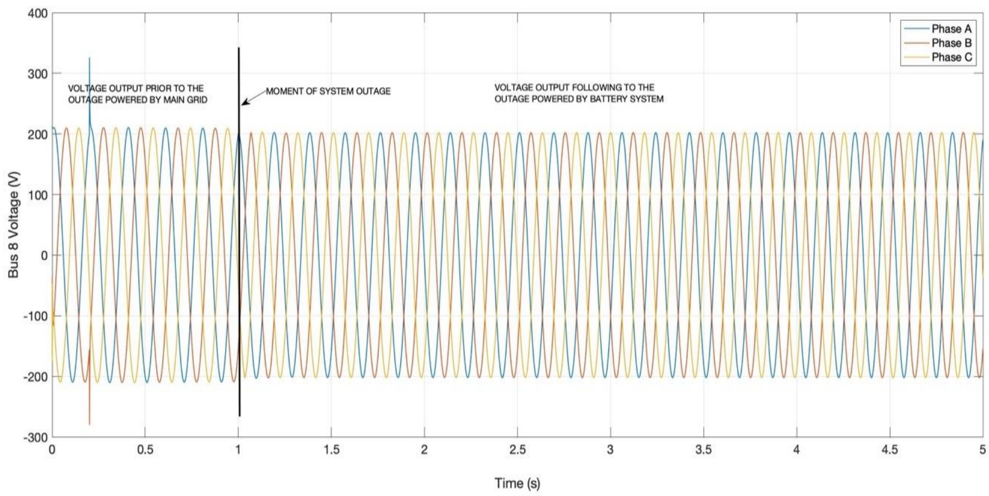

Fig. 7 Three Phase Voltage at Bus 8 with BESS working in islanded mode after 1 s

Fig. 8 represents the second model that has been simulated with both BESS and PV connected to the grid and the combination of the DERs is used to supply uninterrupted power and meet the energy needs of the loads in the distribution network in the event of an outage. Additionally, the characteristics of the PV and BESS during the outage operation has been recorded in Fig. 9. The active power from the DERs in kW is shown in first two plots. The state of charge of the battery can be viewed in the third plot.

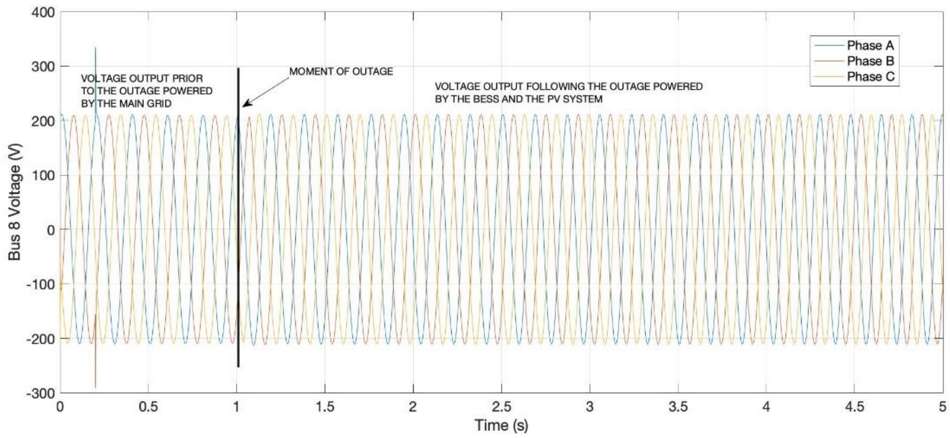

Fig. 8 Three Phase at Bus 8 with BESS/ PV working in islanded mode after 1 s

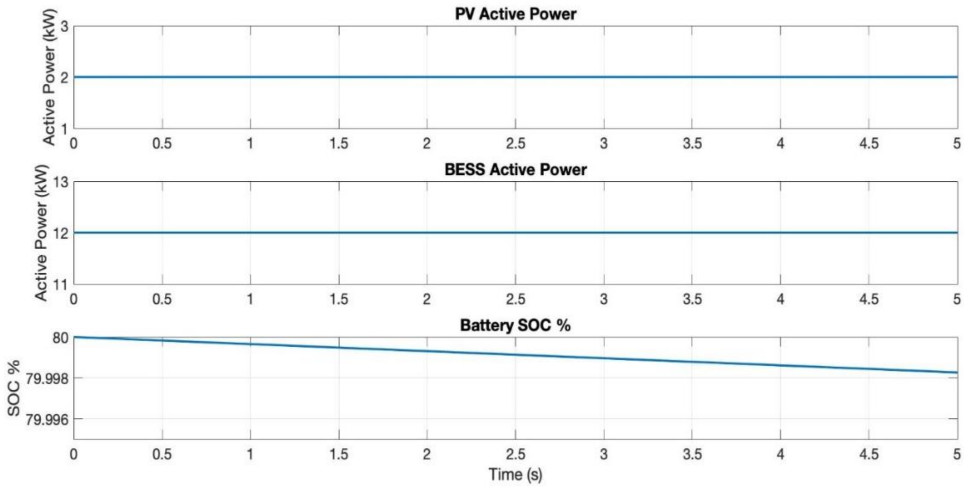

Fig. 9 PV and BESS characteristics

CONCLUSION

In this paper, we have discussed the advantages of employing a battery energy storage-based outage management system in remote locations to handle the power outages in these areas with minimum down time. The traditional methods of connecting another feeder to form a loop are either expensive to implement in these locations or the locations do not have the physical capability to handle the traditional outage management systems. The BESS based OMS connected on the primary end/ the secondary end provides the utility company with a reliable solution to make sure that the residential loads receive the required energy in the upstream outage. Adding other renewable sources, such as the PV system, to supplement the energy stored in the battery proves to be advantageous during long-term outages in remote locations. The simulation results demonstrated that the proposed solution could smoothly switch the customer to be supplied by BESS without power outages.

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